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**Straight Ends for Superconducting Dipole Magnet
Using "Constant Perimeter" Geometry**

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STRAIGHT ENDS FOR SUPERCONDUCTING DIPOLE
MAGNET USING "CONSTANT PERIMETER" GEOMETRY*

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ABSTRACT

The ends of the SSC Dipole magnets are a very critical aspect of the superconducting cable windings needed for this large project. The internal coils, where the radius at the pole is as small as 3/10 of an inch for the first turn, are difficult to form with the very stiff cable, and a high tension is needed.

The curing operation on the coils is performed in a heated forming press which applies an important additional stress on the superconducting wire and insulation. A new design of this sensitive region of the magnets was performed at LBL, and several prototypes were built and tested. In this paper the construction method used to solve some of the most critical problems is exposed along with a description of the experimental work in progress.

INTRODUCTION

The ends of superconducting dipole or quadrupole magnets, mostly those where the bore diameter is less than 5 or 6 times the cable width are difficult to wind due to the small bending radius of the cable around the pole. However, the construction of such magnets with straight ends remains attractive as compared with magnets with flared ends, especially due to hardware simplification and cost reduction.

The main difficulty is still the small bending radius of the superconducting cable the hard way to fit a small bore without additional superconductor degradation and possible turn to turn shorts as well as of the high cable stress and the resulting thickness growth.

One way to ease high stress in cables is to invoke the use of "constant perimeter" during winding.

CONSTANT PERIMETER

By definition, we require both edges of the cable (the inner and outer) to assume the same overall length during winding. As a result, the cable will not bend the hard way reducing swelling and high stress points.

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In producing a constant perimeter path model I would take a thin flat ribbon of elastic material, steel as an example, form it as a 180° loop and try to fit one edge on a cylinder surface as a cable should be around the bore and mark the ribbon perimeter. It is clearly seen that the inner edge of the ribbon on the cylinder is placed axially farther out on the cylinder than the outer edge. As the length of those two edges remains the same, (the ribbon cannot store any strain) the ribbon has to tilt as it comes around. The maximum tilting angle is observed at the loop summit or pole. The amount of tilting is reduced for those turns which emerge close to the midplane. See Fig. 1.

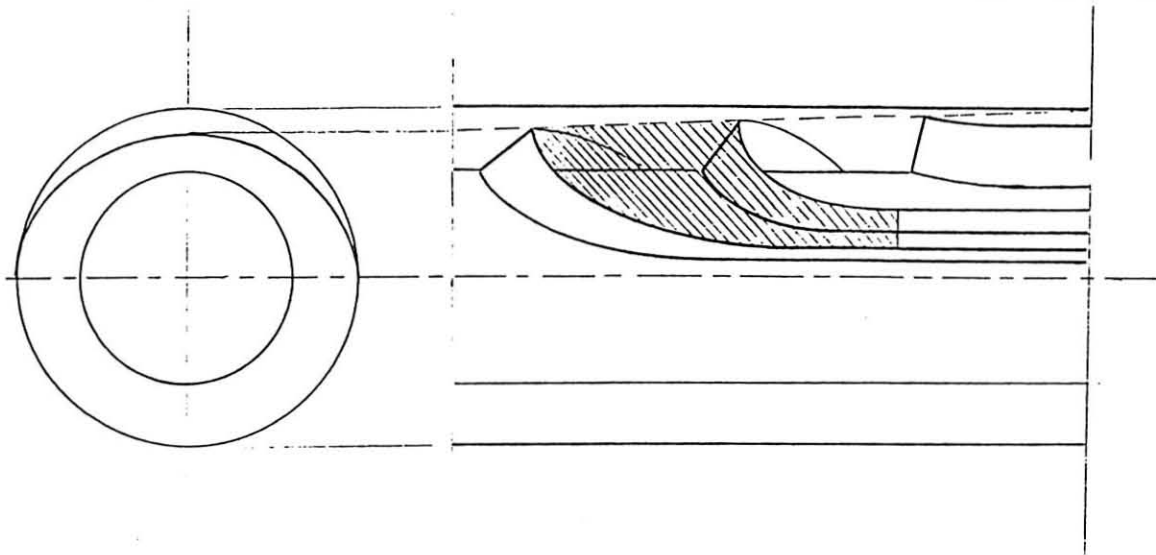


FIG. 1

CIRCULAR INNER CYLINDER

XBL 891-355

The constant perimeter geometry for the cable at the ends of the dipoles has to be accommodated in the space included between two cylinders: the smallest being the inner diameter of each layer and the largest the outside diameter of that layer. If one of these cylinders is circular the other one is necessarily of an odd shape due to the reduction of the apparent cable radial dimension in the tilted areas. Due to the electrical insulation required on the inner surface of the dipole magnet, the best geometry seems to be an elliptical inner shape see Fig. 2.

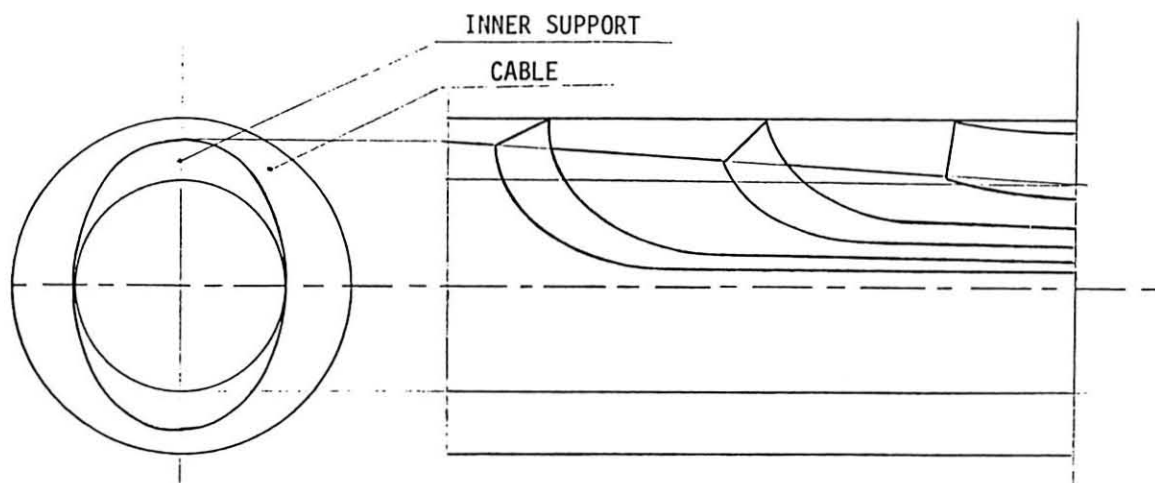


FIG. 2

CIRCULAR OUTER CYLINDER WITH CONOIDAL
INNER SUPPORT

XBL 891-356

DIPOLE WINDING

The superconducting cable is wound the usual way along the straight section and then is forced on conical supports at each end. The cable bundle pattern at the magnet end is a prolongation of the straight section. The copper wedges, however, cannot be used due to the changing shape needed to generate the magnetic field characteristics needed and are replaced with machined spacers.

END SPACERS

- The end spacers have several important functions and characteristics: They should:
- confine the superconducting cable at the required position in order to obtain the magnetic field uniformity needed.
 - contribute to and enhance the dielectric strength of the end windings.
 - exhibit high flexibility during winding without risk of breaking.
 - have reasonable resistance to radiation.

MATERIALS

Several different materials were tried for end spacers, all of them of the plastic nature. The use of plastic spacers was required due to the fact that they had to be fitted in the windings prior to curing. At this stage, the magnet shape and dimensions are slightly different than during the final collaring assembly.

Silicon rubber, epoxy, and fiberglass reinforced epoxy have been used, none of them with full success. A recent experiment performed with LEXAN¹ mold injected parts resulted in the closest possible dimensions and shapes corresponding to the assembled coil. The model parts used to build the molds were hand carved in epoxy resin. Another experiment was performed with machined parts from a LEXAN¹ block using a numerically controlled milling machine programmed with the dimensions of the hand carved models. The resulting end spacers were very similar in shape, but not in cost.

Those end spacers were strong enough to be deformed elastically and inserted in place during the coil winding operation performed at a lower cable tension than with conventional straight end design.

During the press curing which is performed at a temperature close to the LEXAN¹ softening point the end spacers flow and adapt to the superconducting cable bundles. When the coil is cooled, the LEXAN¹ solidifies and fits tightly, filling the entire space between cable blocks and even strands.

This in turn reduces any possible superconducting wire motion due to high Lorentz forces when the magnet is energized.

One model magnet that was built using these type ends was tested and operated satisfactorily.

¹LEXAN is a trade name of a General Electric product.

NEXT DEVELOPMENT

The junction of the conical end support with the straight part of the magnet, should be as smooth as possible then, the cone support thickness at this point should be almost zero. In order to achieve an external pressure resistant assembly we need some kind of internal support: stainless steel tubing was used in the original model magnet. A combination of a stainless steel bore liner with the conical support seems to be one of the next path to explore.

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